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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

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Aircraft Structures Technical Memorandum 569

FLIGHT FLUTTER TEST TECHNIQUES AT ARL

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SUMMARY

Good design of an aircraft ensures that its flutter speed lies beyond its maximum operating speed; however, modification of the aircraft, such as the attachment of external stores to the wings, can lower the flutter speed significantly. In this case it may be necessary to determine experimentally the new flutter speed by means of a series of flight flutter trials. During such trials the aircraft is excited in flight and the measured response analysed to obtain estimates of the structural natural frequencies and damping ratios. This paper describes some of the methods which have been used in Australia to excite aircraft in flight flutter trials, together with the analytical techniques used to reduce the resulting data. Typical results from trials are presented.

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1 INTRODUCTION

Flutter is a self-excited divergent oscillation which has led to the loss of various aircraft since the very early days of flight, but now the common flutter mechanisms are well understood and good design should ensure that new aircraft do not suffer from this instability. It occurs only above a critical airspeed (flutter speed) when sufficent energy is absorbed by the aircraft from the airstream to overcome the structural damping present in one or more modes of vibration, and a structural instability results. Generally the amplitude of vibration grows exponentially until a structural failure occurs. Since flutter arises from the interaction of oscillatory aerodynamics with the aircraft structure, the flutter speed is dependent on the mode shapes and frequencies of the aircraft's normal modes of vibration. Thus changes to the aircraft stiffness and/or mass distributions will alter the flutter characteristics, so any modification to an aircraft must be evaluated from a flutter point of view. A common modification to military aircraft, which can have a profound effect on the flutter speed, is the carriage of external stores under the wings. Such stores, particularly those with high pitching moments of inertia, alter the natural frequencies of modes involving significant wing motion, and perhaps more importantly, change the location of nodal lines. Modifications which give rise to a change in stiffness distribution are less common but one example is the alteration of a fuselage to incorporate a new external doorway. Of course, the effect of such modifications on the flutter speed is not always deleterious (i.e. resulting in a lower flutter speed) but may be beneficial, and some prototype aircraft have been flown initially only with particular external stores, to keep the flutter speed high.

Modern aircraft with fly-by-wire and digital flight control systems can be designed to exhibit certain dynamic characteristics by the use of active control technology which is a computer-controlled feed-back system linking sensors on the aircraft to its control surfaces. A reprogramming of the controlling computer can have a dramatic effect on the flutter speed and must be examined in the same way as the structural alterations described above.

As a first step in determining the new flutter speed, an analysis is carried out. This requires some mathematical description of the structural properties of the aircraft (e.g. a Nastran model) which can be adjusted to reflect the effect of the modification. The other ingredient necessary for the analysis is a description of the unsteady aerodynamic forces, and this is usually calculated. Many approximations regarding the aircraft geometry and the properties of the airflow must

be made to allow this calculation, but for most civil aircraft, which are subsonic, it is a relatively straightforward process. However, for supersonic military aircraft, the transonic flight regime presents problems which have not yet been satisfactorily solved. For aircraft with active controls, the effect of the feed-back loops must be included in the analysis. This means that transfer functions representing the dynamical behaviour of the sensors, filters, actuators, and other electronic and mechanical elements may need to be determined for possible inclusion in the equations of motion. Also, since the analysis is essentially linear, any non-linear elements must be linearised about an appropriate equilibrium value.

When the flutter analysis has been completed, an estimate of the flutter speed at various altitudes is obtained. Because of the assumptions necessary to obtain these estimates, they are discounted by a factor (usually 20% for civil aircraft and 15% for military), resulting in a conservative value, i.e. the final estimate is less than the actual flutter speed, sometimes by a large margin. If the final estimate is so low that it effects the operation of the aircraft (for instance, requiring a placard in the flight manual), a series of flight flutter trials may be recommended in order to demonstrate that flutter does not occur within the required speed range, or, if incipient flutter is detected, to determine the highest safe operating speed at various altitudes. In essence, flight flutter testing is a systematic method of progressing towards an instability boundary while ensuring that the instability is never attained.

2 FLIGHT FLUTTER TEST METHODOLOGY

Whilst on the ground, the aircraft has a fixed set of normal modes of vibration, each with a constant shape, natural frequency and damping ratio (i.e. ratio of damping to critical); however in flight the aerodynamic forces contribute to the inertia, damping and stiffness distributions such that the mode shapes, natural frequencies and damping ratios vary as functions of airspeed, altitude (air density) and Mach number (the ratio of airspeed to the local speed of sound). Flutter occurs when the damping in a mode changes from positive to negative and is often accompanied by two or more natural frequencies coalescing. Thus the ability to determine accurately the natural frequencies and damping ratios of selected modes is important in this form of testing.

2.1 Flight Test Envelope

The range of flight parameters over which the aircraft is expected to operate is called the flight envelope and a typical example is shown in Figure 1. Note that to conform to usual aeronautical practice, altitude is given in units of thousands of feet whilst airspeed is expressed in KCAS (knots, calibrated airspeed). Except at sea level, calibrated airspeed (CAS) is not true airspeed (TAS), i.e. it is not the speed of the aircraft relative to the undisturbed air, but rather it is the reading (following correction for measurement errors) on the aircraft airspeed indicator. CAS and TAS are related by a complex function of the static and total pressures at the flight condition. CAS should not be confused with EAS (equivalent airspeed) which differs from TAS only by the square root of the density ratio (the ratio of air density at the flight altitude to that at sea level). Flutter analyses produce estimates of flutter speeds in units of KTAS which are then usually converted to KEAS, whilst the operation of the aircraft, including flight flutter trials, is in terms of KCAS or KIAS (knots, indicated airspeed). The unsteady aerodynamic forces which are involved in flutter vary in overall magnitude as the square of the airspeed whereas the distribution of these forces over the aircraft varies as a complex function of Mach number (particularly in the transonic flight regime).

Figure 1 indicates that the aircraft in question is permitted to fly only at airspeeds below 525 KCAS and at Mach numbers below 0.9, with the former limitation being the more restrictive below eight thousand feet and the latter above. The point where the combination of the highest airspeed with the highest Mach number is permitted (at eight thousand feet in this case), is usually called the "knee point" and is often the most critical region of the flight envelope from a flutter point of view.

In a flight flutter trial the aircraft is flown through a sequence of test points (i.e. airspeed/altitude combinations), at each of which the aircraft flight parameters are held constant while certain measurements are made. The sequence commences with a benign point (i.e. one at which flutter is extremely unlikely) and proceeds through points of increasing flutter risk until the most critical point is reached. A typical set of test points appropriate to the flight envelope of Figure 1 is shown in Figure 2. The first point in the sequence is generally chosen at high altitude where a given Mach number corresponds to a lower airspeed than at lower altitude, e.g. Mach 0.7 at 25 thousand feet corresponds to 290 KCAS whereas at sea level this Mach number corresponds to 465 KCAS. The first five test points in this example will show the effect of increasing Mach number, but at relatively low

airspeeds so the risk of flutter is still relatively small. The next five points examine the same Mach number progression but at higher airspeeds, so that the unsteady aerodynamic forces are significantly larger, with a correspondingly greater effect on the aircraft natural frequencies and damping ratios. The final five points represent the progression to potentially the most hazardous point in the test. Following the successful completion of the final test point, a single flight along the boundary is made to ensure that no flutter regions exist between the test altitudes. In this example, the test aircraft would commence at 25 thousand feet and Mach number 0.9, and then descend to eight thousand feet keeping Mach number constant, and then continue the descent to sea level at constant airspeed (525 KCAS).

2.2 Aircraft Excitation

At each test point the natural frequencies and damping ratios of selected modes of aircraft vibration must be determined from measured data. In effect, the aircraft must be excited in flight to provide sufficient amplitude in the required modes to allow this determination to be performed accurately. The excitation may be deterministic which implies that the exciting force may be measured, or it may be non-deterministic which means that although the force is not measured, assumptions as to its properties (often in a statistical sense) are made. The desirable properties of an excitation system are such that it

- does not alter the aircraft mass or stiffness distribution
- does not alter the aerodynamic flow field around the aircraft
- excites all the vibration modes of interest
- does not jeopardise aircraft safety
- does not adversely affect the aircraft's handling qualities
- permits measurement of the exciting force (if deterministic)
- facilitates changes to force level and/or frequency range
- provides repeatable excitation
- be inexpensive to purchase and operate
- facilitates installation and removal.

Of course, it is extremely difficult to design a system with all these qualities so some compromise is necessary, but the flutter test engineer must ensure that the excitation system does not alter the characteristics of the test aircraft to such an extent that the flight tests become meaningless.

The requirement that all the modes of interest be excited implies that the exciting force must act on the appropriate parts of the structure (e.g. it may be difficult to excite a fin mode by shaking the wing), and that the excitation must be spectrally rich, i.e. it should contain

energy over a sufficiently wide frequency range to encompass all the required modes. Various excitation time-histories have a broad band power spectrum, e.g. frequency sweep, impulse and random, each with advantages and disadvantages, and a choice is made to suit the particular test under consideration.

2.2.1 Unmeasured excitation force

The most commonly used non-deterministic excitation is atmospheric turbulence because it requires no alteration to the test aircraft. It is normally assumed to have energy distributed relatively uniformly over the frequency range of interest, but with an overall magnitude that varies both spatially and temporally. It is not so effective however for aircraft with high wing loading (i.e. for aircraft with wing areas small in comparison to the total aircraft mass), or in cases where some of the modes of interest consist mainly of motion of non-aerodynamic components (e.g. pitch and yaw of under-wing stores).

Another commonly used forcing method is the use of pilot inputs. In this technique the pilot generally applies a sharp "rap" to the normal aircraft controls, attempting to approximate an impulse function; however the aircraft flight control system generally attenuates the higher frequency components severely such that it is usually very difficult to excite modes with natural frequencies above about four hertz. Also, the controls can only be used in their normal operating mode, so the ailerons, for instance, cannot be moved symmetrically to excite the wing fundamental bending mode.

There are commercially available devices termed "bonker rockets" which may also be used to apply an impulsive force to an aircraft in flight. These small rockets are attached to suitable locations on the aircraft structure and, when ignited, produce a given force output for a specified duration. The impulse duration is selected to maximise the excitation energy in a particular frequency band. These devices suffer from the safety problems associated with all explosives, especially in the event of a malfunction. It is also difficult to excite modes over a broad frequency range with a single device, and this may adversely affect the cost and duration of the test.

An alternative, developed at ARL, is a device which ejects water using compressed air as the propellent. The force level is dependent on the velocity of the ejected water whereas the pulse duration depends also on the total volume of water ejected. The device is capable of being recharged in flight for multiple excitations, and the force and pulse duration are similarly adjustable in flight, which ,together with a low

operating cost and negligible safety hazard, make it a most useful excitation system.

A final example of a simple excitation system in which the excitation force is not measured is a single out-of-balance mass rotated by an electric motor. As the motor speeds up and slows down, a relatively wide frequency range is covered, but with the disadvantage that the force level increases with the square of the rotational speed (frequency). Thus if the amount of out-of-balance is selected to provide adequate excitation for the low frequency modes, then it is generally excessive for the higher ones.

2.2.2 Measured excitation force

This form of excitation is less commonly used because it requires the instrumentation necessary to measure the applied force, or at least to transduce a quantity from which the applied force can be calculated. An example of such a system involves the use of a gust probe to measure the incident gust field (not a trivial task since the resulting motion of the aircraft affects the gust probe readings), and then calculating the gust forces from this velocity field. ARL has not used this particular excitation technique for flight flutter testing.

As mentioned above, the force resulting from a rotating out-of-balance mass increases as the square of the rotational velocity (frequency). If, however, the effective out-of-balance is reduced as the rotational velocity is increased, the resulting force can be made more constant over the frequency range. For instance, consider a frequency sweep in which the frequency increases from zero to a maximum and then returns to zero. When the sweep starts, the out-of-balance should be a maximum and should reduce as the sweep proceeds until at the highest frequency the out-of-balance reaches a minimum. Upon reaching this upper limit, the frequency then commences to decrease requiring the out-of-balance to increase to reach its maximum when the frequency once more attains its minimum value (zero). This can be achieved by having two co-axial out-of-balance masses rotating at slightly different rates such that when the masses start to rotate, the two out-of-balances are adjacent (giving maximum net out-of balance). As the sweep proceeds the two out-of-balance masses separate, thus reducing the net out-of-balance at a rate such that when the masses reach maximum rotational velocity the out-of-balances are exactly opposite (giving minimum net out-of-balance). Having reached its maximum, the frequency then decreases and the two out-of-balance masses approach each other such that the net out-of-balance increases. When the sweep has ended, the two out-of-balances are once more adjacent but one mass has made one

complete revolution less than the other. Provided that for each out-of-balance mass, the instantaneous velocity and position are measured, the instantaneous centrifugal force can be calculated. ARL has used such an excitation system very successfully in a series of flight flutter trials; however such a system is relatively inflexible in so far as it is difficult, once the device has been built, to alter the force level, the swept frequency range or the sweep time. It is also incapable of producing random excitation.

Another system used by ARL utilised oscillating aerodynamic vanes, supported on load cells, to produce the excitation. The force was transduced directly and the controlling micro-processor could easily be programmed to alter force level, sweep rate and/or frequency range. Such a system is also capable of producing amplitude-limited pseudo-random excitation although ARL used it only for frequency sweeps. A self-calibration feature allowed the device to determine at each test point, the positive and negative angles at which the vanes stalled, the angle of zero force and the angle of rotation necessary to obtain a given force level.

2.3 Instrumentation

Of course, the test aircraft must have the instrumentation necessary to measure the basic flight parameters (such as airspeed and altitude) with sufficent accuracy for test purposes. However there is also the need to determine the excitation force (if required) as well as the aircraft structural response to this excitation. The instrumentation for force determination will depend on the method of excitation and whether the force is measured directly or whether it is calculated from other measurands. Structural response is generally measured either by strain gauges, by accelerometers or by a combination of the two. ARL has favoured the use of accelerometers because of their greater ease of fitment to an existing aircraft, and a greater ease of calibration. In particular, servo-accelerometers have been used because their greater sensitivity means that amplifiers are not required, and their static capability means they can be easily calibrated against the earth's gravitational field. Although servo-accelerometers do not have the high frequency capability of the piezoelectric variety (usually about 300 Hz as opposed to tens of thousands of Hz), the frequency range of interest in a flight flutter test rarely extends beyond about 50 Hz. If the accelerometers are to be sensitive to all the required modes, care must be exercised in selecting their location. If any are placed on, or near, a nodal line, those accelerometers will not provide a reliable estimate of the response in that mode. Consequently accelerometers are usually placed at extremities (wing tips, tail tips, top of the fin, in

the nose of external stores, front and rear of the fuselage etc.) where nodal lines are unlikely to occur and where there will be response in all the modes important for flutter.

The signals from all the various sensors must be stored on an on-board recorder and/or telemetered to a ground station, in either analogue or digital format, following some form of signal conditioning including filtering. The advantage of telemetry is that with it, data measured at one test point can be analysed to provide a clearance for the aircraft to proceed to the next point with a minimum of delay. Thus the cost of the telemetry equipment can be offset against the savings inherent in the more efficient use of the test aircraft.

2.4 Data Analysis

The task of the analyst is to determine from the measured data, estimates of the natural frequencies and damping ratios of all the modes of interest at each test point. The dual requirements of the analysis process are that it be accurate, as the safety of the test aircraft depends on this, and also that it be efficient, i.e. in order to achieve this accuracy only a minimum amount of data need be collected at each test point. Various analysis techniques have been used at ARL depending on the modal density (the number of natural frequencies in a given frequency range) and the form of excitation used. Modal density can be reduced by taking advantage of symmetrically located accelerometers. If the signals from two such accelerometers (e.g. an accelerometer on the port wing tip and one on the starboard) are added, then the resultant will contain information only on the symmetric modes with a consequent decrease in modal density. Similarly the signals may be differenced for the antisymmetric modes.

A simple analytical technique which may be used when the aircraft experiences random excitation is the Random Decrement Method (Reference 1) which uses a form of averaging in the time-domain to produce a pseudo impulse-response of the aircraft, often called a randomdec signature. Estimates of the structural natural frequencies and damping ratios could be determined from this signature by fitting complex exponentials to it, but the necessary least squares process would be non-linear and convergence to a global minimum could not be guaranteed. Instead, an auto-regressive model of high order (necessary to avoid bias) is used to obtain the characteristic values (frequencies and dampings) from the signature. The complex amplitude of each mode is obtained by a linear least squares process. Separating the linear and non-linear parts of the problem in this way leads to a formulation which can be solved by very efficient algorithms, especially when advantage is taken of the

assumed stationarity of the excitation. The Random Decrement algorithm used to obtain the randomdec signature is particularly easy to implement but it suffers from a low efficiency.

Another analysis technique which ARL has used with random excitation is the Maximum Entropy Method (Reference 2) which in effect utilises the same process described above for analysing the randomdec signature, but applied to the raw data without going through the intermediate step of forming the signature. This method has the advantage of "super-resolution" which means that the frequency resolution is much better than that obtainable from procedures based on the standard Fast Fourier Transform (FFT). This is important when modal density is high. It also has high "statistical efficiency" which means it should produce results with a low variance for a given length of data. The implementation used by ARL incorporates a module for handling the spurious data values which often contaminate telemetered data.

If the excitation is measured, then transfer function analysis techniques may be used, particularly if the modal density is relatively low. In this approach Fourier transforms are used to form a transfer function between the response (either a single accelerometer signal or a linear combination of accelerometer signals) and the excitation force. Provided the modal density is not too high, the frequency range is broken down into a series of intervals, each of which has either one or two natural frequencies in it. A function of the right analytical form is then fitted by a weighted least-squares process to the the transfer function in each interval to extract the required values of natural frequency and damping ratio. This process has the advantage of requiring little computing power (especially if the Fourier transforms are determined by a dedicated FFT machine) but it suffers from the disadvantages that it is not very robust against measurement noise, and also that long data records are necessary to give the required frequency definition. Finally, there is inherently no more information contained in the frequency domain description of the structure (the transfer function) than there is in the time domain, so the use of Fourier transforms (or any other intermediate transformation) should not be necessary.

To improve the performance of the analysis methods in terms of the dual requirements of accuracy and efficiency, the analytical techniques of modern signal processing methods have been utilised to produce a program based on the ARMAX (Auto-Regressive Moving Average for eXogenous input) method (Reference 3). This method is a generalisation of the Maximum Entropy approach to allow for non-stationary, measured excitation, and consequently it also has the advantages of super-resolution and high

statistical efficiency.

As a further refinement, a suite of computer programs based on recursive maximum likelihood (Reference 3) has been developed. This method differs from ARMAX in the way in which the noise is modelled. Even though the aircraft is excited by the measured deterministic force, since it is flying through a real atmosphere there is simultaneously unmeasured, non-deterministic excitation (turbulence). ARMAX methods increase the size of the model to account for this noise, whereas the recursive maximum likelihood method models this noise in such a way as to minimise the number of parameters describing the system. In effect it produces unbiased, minimum-variance estimates from the minimum order model.

In all the above, the analysis techniques are based on a single-input single-output model, i.e. each accelerometer, or each linear combination of accelerometer signals, is treated as independent of all the others. This means, for instance, that the analysis of the signals from two different accelerometers could result in two different estimates of a particular natural frequency. The next extension to the analytical tools available to ARL for flight flutter trials analysis is the development of a computer program based on the single-input multi-output ARMAX method. In this computationally-intensive method the signals from all the accelerometers are processed simultaneously to produce one consistent estimate of each natural frequency and damping ratio.

3 TYPICAL RESULTS

Figure 3a shows a 1.25 second segment of data collected from a single accelerometer during a flight flutter trial. The aircraft was undergoing turbulence excitation and the brief time history shows the random nature of the response. Although shown as a continuous line the data are discrete, having been digitised at 400 samples per second. Approximately 120 seconds of data were recorded giving a total record length of about 50000 samples. Following processing using the Random Decrement algorithm, the signature shown in Figure 3b was obtained. The final step in the analysis process is the extraction of natural frequencies, damping ratios and complex amplitudes by the method described above in Section 2.4, and the curve generated from these values is shown in Figure 3c for direct comparison with Figure 3b.

When the aircraft was excited by deterministic excitation during the same flight trial, an analysis based on transfer function theory was used and Figure 4 presents a typical result. The real and imaginary

parts of the transfer function relating an accelerometer output to the exciting force are shown in Figure 4a for the frequency range of interest (5 Hz to 14 Hz) which includes a number of natural frequencies. Again, although the curves are drawn as continuous lines, they are actually sequences of discrete points. The data (accelerometer and force signals) were digitised at 128 samples per second and formed into blocks of 1024 samples for the FFT process, giving a frequency definition of 0.125 Hz. The transfer function estimate shown was obtained by taking the ratio of the average cross power spectrum to the average input power, the averaging being over 20 ensembles (i.e. requiring 160 seconds of data). As stated above in Section 2.4, the transfer function analysis method used at that time was limited to frequency intervals containing at most two natural frequencies. Figure 4b shows one such interval (8.3 Hz to 10.9 Hz) with the measured transfer function plotted on the complex plane as a series of points. The fitted analytical form is shown on the same figure as a continuous line.

The Maximum Entropy Method has been applied to data gathered in a flight flutter trial. Figure 5a shows a typical segment of accelerometer data taken from a block of 2500 points digitised at 50 samples per second. The full data block was analysed as described above, returning the coefficients of the auto-regressive model (in this case, 45th order) from which estimates of the required structural parameters can be derived. Figure 5b shows the predicted accelerometer response derived from this model and although it is quite similar to Figure 5a, they are not identical. The difference between the two should, if the model adequately represents reality, be "white noise" which, by definition, is unpredictable. That the residual is in fact white noise can be demonstrated by examining the autocorrelation function, and this is presented in Figure 5c for the first 200 lags, where it can be seen that the function is essentially zero for all non-zero lags.

As the flight flutter test proceeds, estimates of the structural natural frequencies and damping ratios are obtained at successive test points. Figure 6 shows a typical variation of natural frequency and damping ratio for one mode as a function of Mach number at constant altitude. Estimated parameters were obtained from two separate excitation/analysis procedures, namely turbulence with Random Decrement and measured inertial excitation with transfer function analysis. This figure shows that although the two excitation/analysis procedures provide very similar estimates of the modal frequency, that resulting from turbulence/randomdec is always slightly higher. This may result from structural non-linearities coupled with the different modal amplitudes resulting from the turbulence and deterministic excitations. The

variation of estimated damping ratio with Mach number is less smooth showing the greater uncertainty in this parameter. Also the difference between the results from the two methods is more variable and not the almost constant difference evident in the natural frequency values.

Table 1 presents a comparison between natural frequencies obtained from a theoretical flutter analysis with those measured in an actual flight flutter test. Not all the theoretically predicted modes were measured in the flight trial, either because the excitation did not excite them to sufficient amplitude or because there were no transducers located appropriately to measure them. None of the missing modes was considered important as far as flutter was concerned. It can been seen from Table 1 that the agreement between the measured and theoretical frequencies is excellent at each altitude. Such agreement increases the confidence in the theoretical flutter predictions and thus reduces the requirement for flight flutter testing.

4 CONCLUSIONS

Flight flutter testing is an experimental process for demonstrating freedom from flutter and is usually necessary when a theoretical analysis shows an insufficent flutter margin. It is essential in such tests that every important mode is adequately excited and that transducers be located to measure the response in each of these modes. The cost of these trials depends directly on the number of test points flown and on the length of time spent at each test point, and both these can be decreased by using data analysis processes that are as statistically efficient as possible. This paper has described some of the excitation techniques and analysis methods used by ARL in flight flutter tests of both military and civil aircraft.

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MODE	3,000 ft		30,000 ft	
	Predicted	Measured	Predicted	Measured
1	5.4	5.2	4.8	4.8
2	7.2	7.4	6.5	6.8
5	7.3	7.2	7.4	7.3
6	8.1	8.0	-	-
7	7.9	8.0	8.1	8.0
8	8.5	8.5	8.5	8.5
9	8.4	8.5	8.5	8.5
10	9.5	9.7	9.0	9.2
11	11.2	12.0	10.9	11.6

Table 1. Comparison of predicted and measured natural frequencies (Hz) at two altitudes.

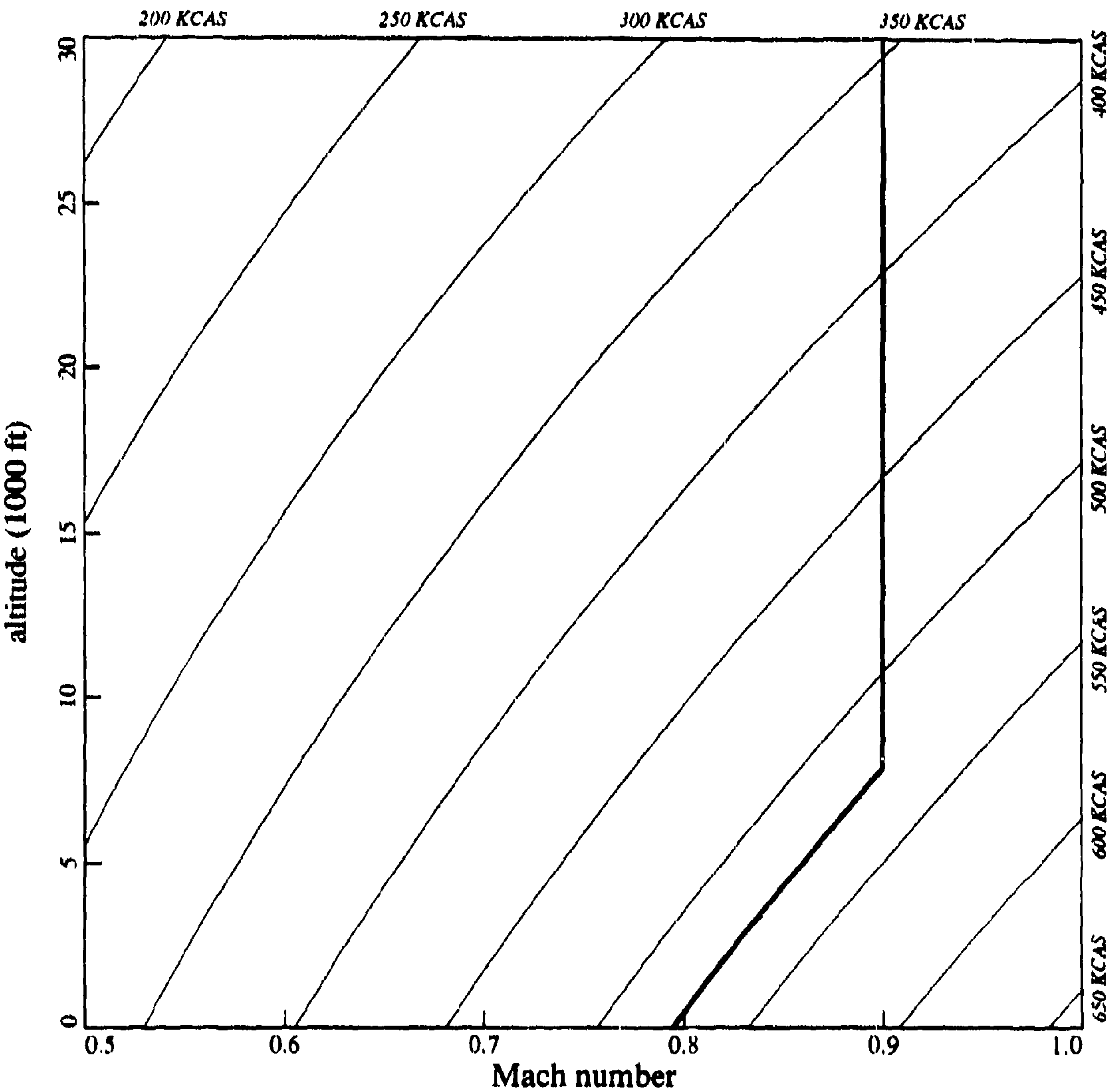


Figure 1. Typical flight envelope

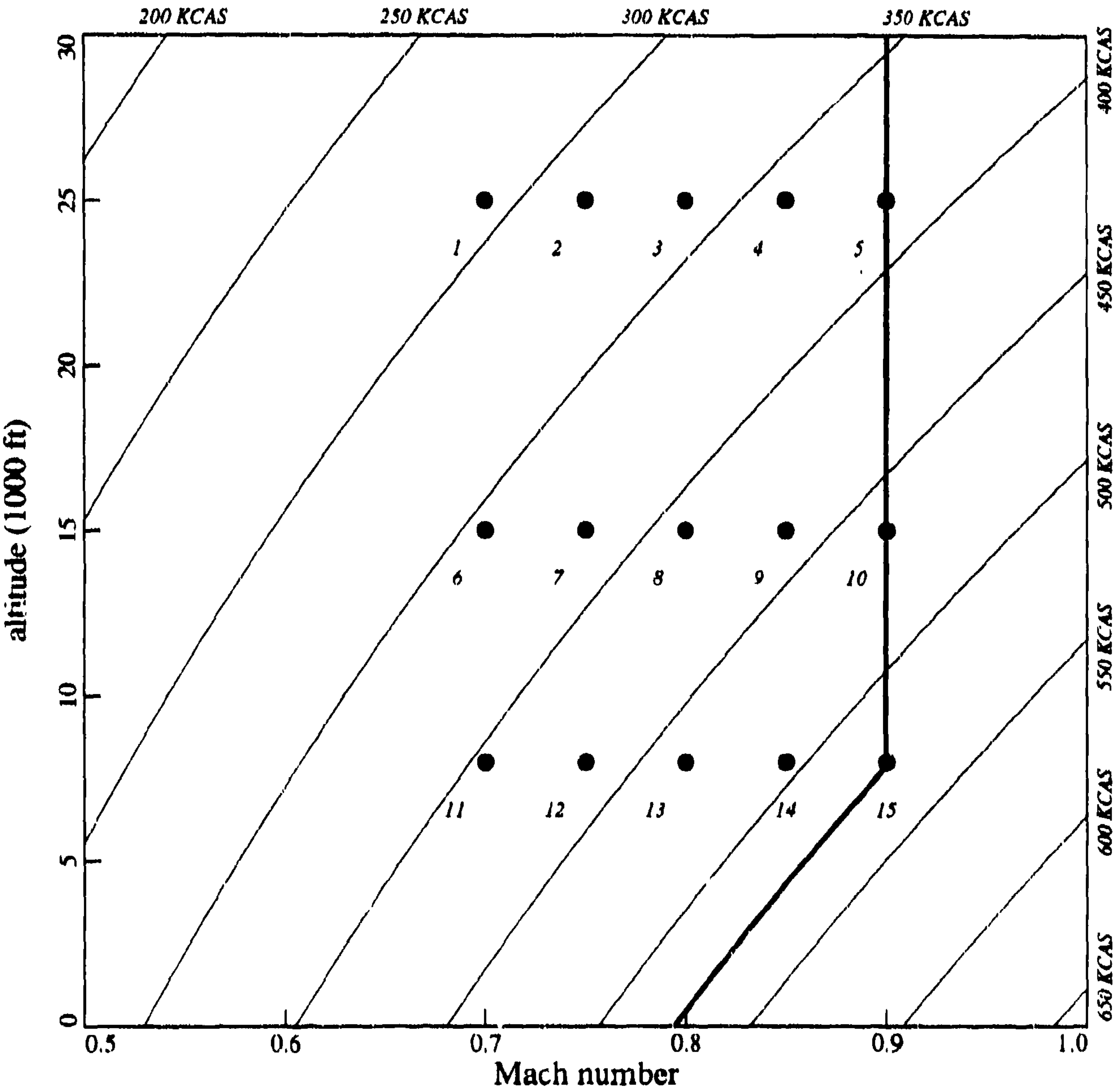
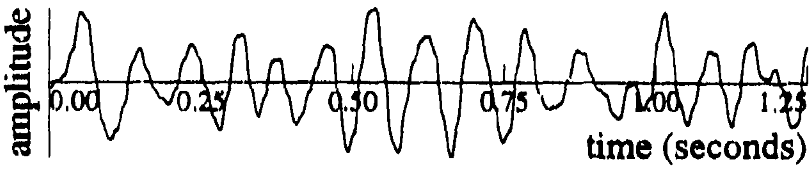
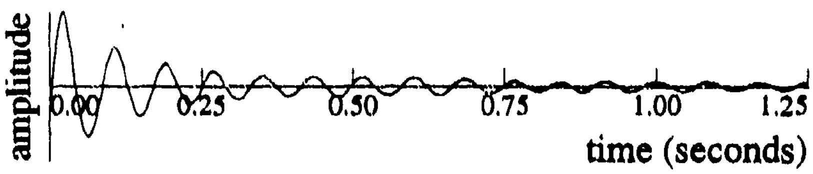


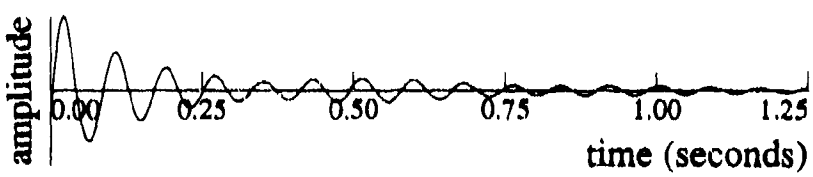
Figure 2. Typical test points suitable for this flight envelope



(a) Typical segment of accelerometer response

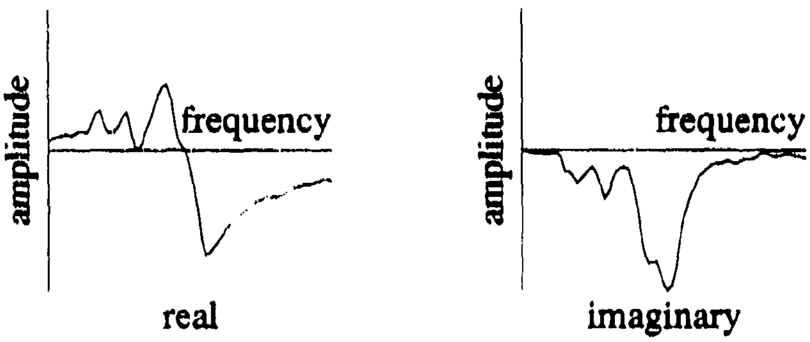


(b) Random Decrement signature

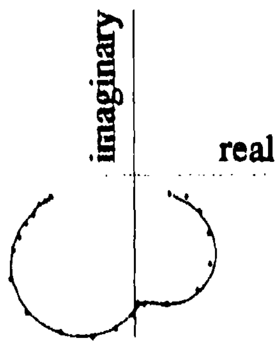


(c) Fitted curve

Figure 3. Random Decrement analysis

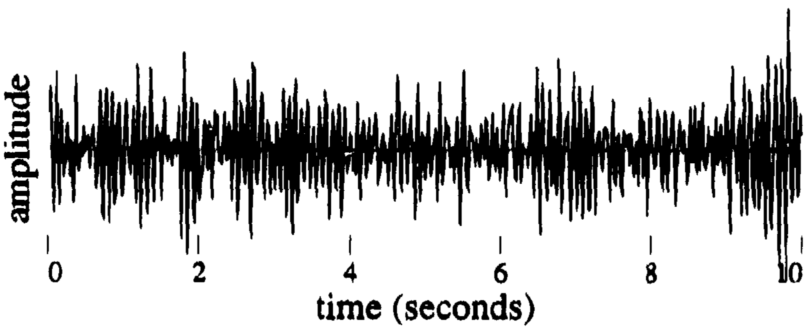


(a) Measured transfer function in the range 5-14 Hz

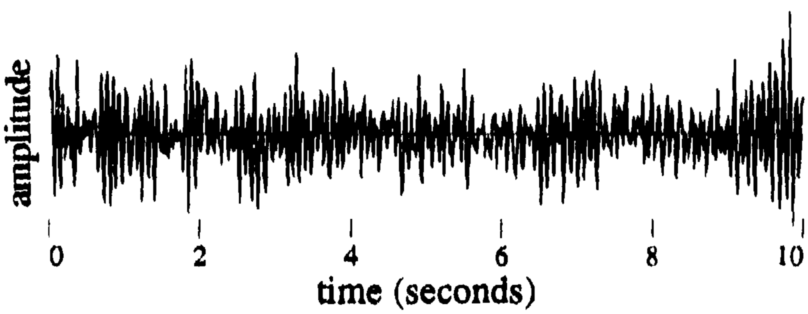


(b) Measured transfer function and fitted curve in the range 8.3-10.9 Hz

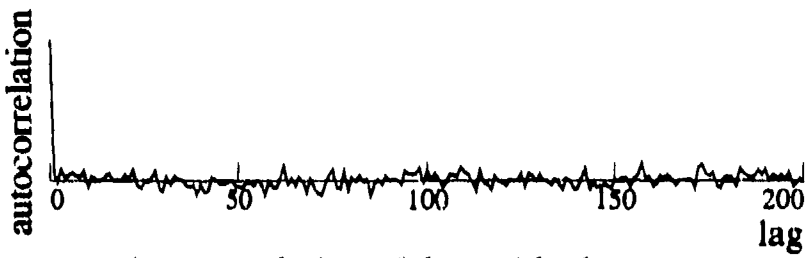
Figure 4. Transfer function analysis



(a) Typical segment of accelerometer response



(b) Predicted response



(c) Autocorrelation of the residual

Figure 5. Maximum Entropy analysis

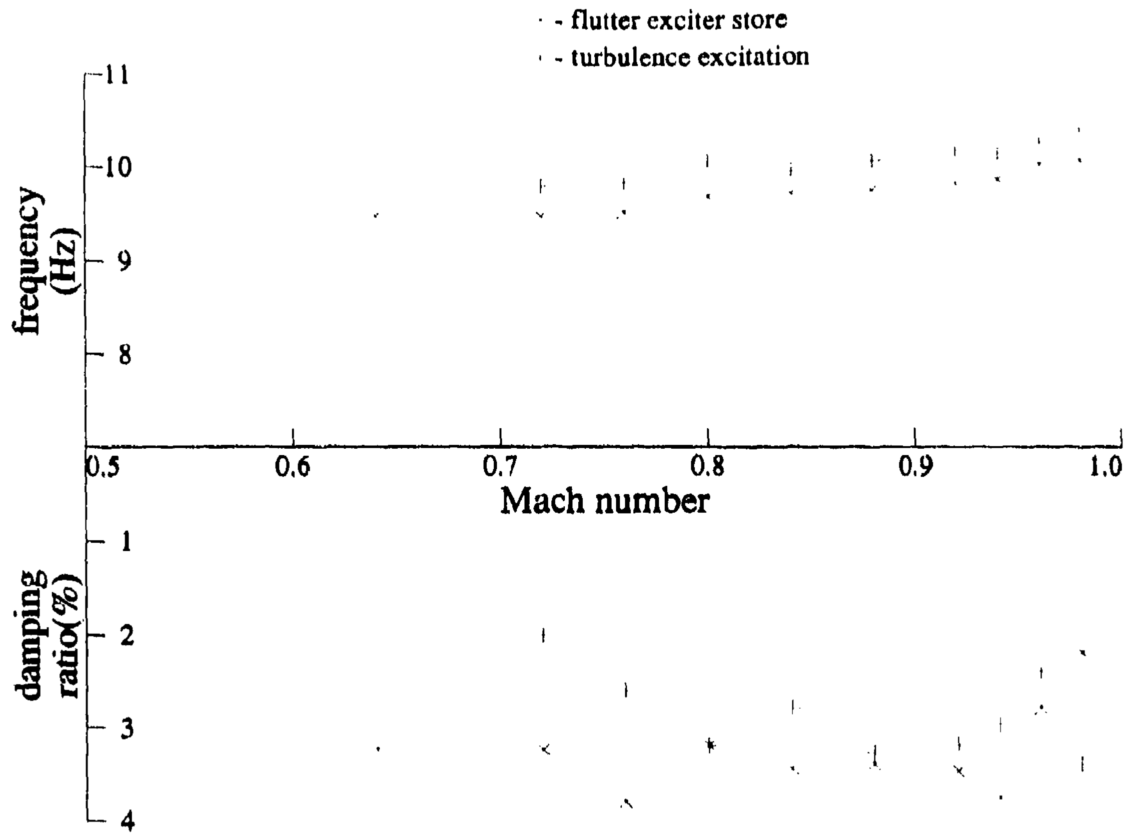


Figure 6. Comparison of two excitation methods

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Good design of an aircraft ensures that its flutter speed lies beyond its maximum operating speed; however, modification of the aircraft, such as the attachment of external stores to the wings, can lower the flutter speed significantly. In this case it may be necessary to determine experimentally the new flutter speed by means of a series of flight flutter trials. During such trails the aircraft is excited in flight and the measured response analysed to obtain estimates of the structural natural frequencies and damping ratios. This paper describes some of the methods which have been used in Australia to excite aircraft in flight flutter trials, together with the analytical techniques used to reduce the resulting data. Typical results from trials are presented.

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